REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Dec 97	Final

4. TITLE AND SUBTITLE
Competitive Tradeoff Modeling: Methodology, Computation, and Testing

5. FUNDING NUMBERS
DAAH04-95-1-0149

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 34385.10-MA-SDI

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This final report documents progress achieved under the cited grant in the following four research topics: (1) Cost-effective dynamic resource allocation in stochastic environments; (2) Incorporating uncertainty in analytic force-on-force models; (3) Developing methodologies for estimating marginal effectiveness of systems and units; (4) Supporting studies in foundation areas contributing to the above.

14. SUBJECT TERMS	15. NUMBER IF PAGES
Force-on-force models; attrition models; combat models; simulation optimization; variational inequalities; economic equilibrium models	9
	16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Competitive Tradeoff Modeling: Methodology, Computation, and Testing

FINAL REPORT

Stephen M. Robinson
December 1997

U. S. ARMY RESEARCH OFFICE

Grant No. DAAH04-95-1-0149

University of Wisconsin—Madison

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Contents

1 Problem studied

The work under this grant focused on the following research tasks:

1. Cost-effective dynamic resource allocation in uncertain (stochastic) environments, with applications to areas such as project management, manufacturing, communications and high-speed data processing.

2. Incorporating uncertainty in analytic force-on-force models for system evaluation.

3. Developing methodologies for estimating marginal effectiveness of systems and units functioning independently or as parts of larger forces, in situations including:

   - Estimation under conditions of uncertainty in the performance capability of systems and units.
   - Estimation under conditions of uncertainty in the environments in which the systems and units will be employed or engaged.
   - Evaluation of systems and units that do not directly kill the enemy.
   - Evaluation under conditions in which the measure(s) of effectiveness are other than destruction of the enemy: *e.g.,* operations other than war.
   - Evaluation under conditions of employment in missions other than those for which the units or systems were designed.

4. Supporting studies in foundation areas, such as nonsmooth analysis and stochastic optimization methods, that contribute to the above research areas.

2 Summary of results

Progress was made during the course of the grant on all tasks described in Section 1. In this section we briefly summarize the progress; further detail is given in the cited references.

Progress on Task 1 included a new method for allocating buffer resources in tandem manufacturing lines. This technique is described, analyzed, and illustrated in the Ph.D. dissertation of G. Gürkan [1].

Progress on Task 2 resulted in a methodology tentatively called dynamic scenario analysis. This is currently written up in an unpublished working paper, part of which was presented by invitation at the National Meeting of the Institute for Operations Research and the Management Sciences, San Diego, CA, May 1997.

Progress on Task 3 resulted in an improved marginal valuation methodology, which is developed, justified, and illustrated in the Ph.D. dissertation of D. K. Lee [3]. Some of the results from this work were presented by invitation in the keynote address for the Army Research Office Workshop on "Analytic Combat Modeling and Simulation," held at Research Triangle Park, NC, 10–11 March 1997. Follow-on work in cooperation with the U. S. Army Concepts Analysis Agency, Bethesda, MD is currently in progress. Other work in this area included a Bayesian approach to system testing, described and illustrated in [6].

Progress on Task 4 resulted in several papers and one Ph.D. dissertation. We summarize this work here, and refer to the "References" section for additional detail.

- Work on solution of stochastic variational inequalities produced the dissertation of Özge [4], which presented and justified a new method for numerical solution of stochastic variational inequalities. This method was applied to option pricing in [2].

- A homotopy method for solving deterministic variational inequalities was presented in [11]. This method appears to be very robust, and it has been successful in solving some problems that could not be solved by popular packages such as the PATH solver. This appears to be particularly true of certain classes of force modeling problems; exhibits of problems solved by the method of [11] but not solvable by PATH were given in [3] and were also described at the ARO workshop mentioned above.

- A reduction methodology for variational inequalities of a certain form was developed and justified in [9]. This method when applied to a computational example (a Walrasian equilibrium model due to Scarf) yielded a reformulation that reduced the solution time by a factor of 50.

- A new approach to duality for optimization problems and variational inequalities was developed and presented in [10]. This approach is an

attempt to generalize the method used in [9], described above, to see if it may be applicable to more general types of problems.

- A convergence rate result for the powerful and widely used bundle method for nonsmooth convex optimization was developed and presented in [7]. This result shows that the bundle method is linearly convergent in major iterations, provided that the convex function being minimized belongs to a certain reasonable class of "nice" functions.

- A new approach to verifying stability for certain saddle problems representable as variational inequalities was given in [5]. This approach can be used to predict when the problems involved remain well behaved under small changes in the data. It can be applied to certain games and equilibrium models, as well as to problems from nonlinear optimization.

3 Publications and technical reports

Work under this grant resulted in five papers published or accepted for publication, one paper that appeared as a portion of a technical report published by the U. S. Army Research Laboratory, and two papers submitted for publication and favorably refereed. These papers are currently being revised for resubmission. In addition, three Ph.D. dissertations acknowledged support from this grant. A complete list of all of these works is given under "References" below.

4 Reportable inventions

There were no reportable inventions during the course of this work.

5 Participating scientific personnel

The following participating scientific personnel received support from this grant:

- Stephen M. Robinson, Professor (Principal Investigator)

- Gül Gürkan, Research Assistant. Ms. Gürkan received the degree of Doctor of Philosophy (Industrial Engineering) in 1996.
- Dong Keun Lee, Research Assistant. Major Lee received the degree of Doctor of Philosophy (Industrial Engineering) in 1996.
- A. Yonca Özge, Research Assistant. Ms. Özge received the degree of Doctor of Philosophy (Industrial Engineering) in 1997.

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